IN THE SPECIFICATION:

Please add on Page 1, before the heading "Background of the Invention", the following new paragraph. :

CROSS REFERENCE TO RELATED APPLICATION

This application is a Continuation of U.S. Application No. 09/448,536, filed November 22, 1999, which is a continuation of U.S. Application No. 08/709,012, filed September 6, 1996, now U.S. Patent No. 6,024,576, each of which is incorporated herein by reference in its entirety.

Please replace the paragraphs below for the paragraphs originally filed. Additions are underlined and deletions are shown in strikethrough text.

Replace the existing paragraph starting on Page 5, Line 2 with the following new paragraph.

The present invention provides a mechanical interface apparatus and method which can provide highly realistic motion and force feedback to a user of the apparatus. The preferred apparatus includes a gimbal mechanism which provides degrees of freedom to a user manipulatable object about a remote pivot ~~poin~~ point such that the gimbal mechanism is entirely within a single hemisphere of a spherical workspace of the user object. In addition, a band drive mechanism provides mechanical advantage in applying force feedback to the user, smooth motion, and reduction of friction, compliance, and backlash of the system. The present invention is particularly well suited to simulations of medical procedures using specialized tools, as well as simulations of other activities, video games, etc.

Please replace the existing paragraph starting on Page 6, Line 25 through Page 7, Line 2 with the following new paragraph.

The interface apparatus of the present invention provides a unique gimbal mechanism having a remote pivot point that allows a user manipulatable object to be positioned on one side of the pivot point and the gimbal mechanism entirely on the other side of the pivot point. This provides a greater workspace for the user object and allows the mechanism to be protected and concealed. In other embodiments, the remote pivot point allows the user object to be rotated about the center of the object ~~whilem~~ while advantageously allowing the user to completely grasp the object. Furthermore, the present invention includes easy-to-assemble band drive mechanisms that provide very low friction and backlash and high bandwidth forces to the user object, and are thus quite suitable for high precision simulations such as medial procedures. The structure of the apparatus permits transducers to be positioned such that their intertial contribution to the system is very low, thus enhancing the haptic response of the apparatus even further. Finally, a simulation process allows for realistic simulation of precise procedures such as epidural anesthesia. These advantages allow a computer system to have more complete and realistic control over force feedback sensations experienced by a user of the apparatus.

Please replace the existing paragraph starting on Page 13, Line 8 with the following new paragraph.

User object 44 is coupled to apparatus 25 and is preferably an interface object for a user to grasp or otherwise manipulate in three dimensional (3D) space. One preferred user object 44 is a needle 18, as shown in Figure 1. Shaft 28 of needle 18 can be implemented as part of linear axis member 40. Needle 18 may be moved in all three degrees of freedom provided by gimbal mechanism 38 and linear axis member 40. As user object 44 is rotated about pivot point P and axis B, floating axis E varies its position. Other types of user objects 44 can also be provided for use with mechanical apparatus 25 as described above. Other embodiments for an interface apparatus are found in co-pending U.S. Patent ~~Application Serial No. 08/374,288, atty. Docket number IMM1P005~~ No. 5,731,804, filed 1/18/95, assigned to the assignee of the present

invention and incorporated herein by reference in its entirety.

Replace the existing paragraph starting on Page 14, Line 5 with the following new paragraph.

Unlike typical spherical mechanisms used for user interface applications, gimbal mechanism 38 includes a remote pivot point P that does not touch any portion of the gimbal mechanism. Thus, it is possible to make gimbal mechanism 38 a "hemispherical mechanism", i.e, the gimbal mechanism 38 is positioned entirely within one hemisphere of the sphere. This is demonstrated by dashed line 60, which designates a line extending through the center of a sphere, which is at pivot point P. The entire gimbal ~~mechanism38~~ mechanism 38 is on one side of line 60, while the user manipulable object 44 is on the other side of point P and line 60 (except, of course, shaft 28, which must connect the user object 44 with the mechanical apparatus 25). This allows user object 44 a full range of movement in its own hemisphere without being obstructed by any portion of the mechanical apparatus 25.

Please replace the existing paragraph starting on Page 16, Line 1 with the following new paragraph.

Gimbal mechanism 62 provides two degrees of freedom to an object positioned at or coupled to the remote pivot point P. An object 44 can be rotated point P in the degrees of freedom about axis A and B or have a combination of rotational movement about these axes. As ~~exlaind~~ explained above, point P is located remote from gimbal mechanism 62 such that point P does not touch any portion of the gimbal mechanism 62.

Replace the existing paragraph starting on Page 20, Line79 with the following new paragraph.

Optionally, additional transducers can be added to apparatus 25' to provide additional degrees of freedom for object 44. A laparoscopic tool and catheter is described in copending

U.S. Patent ~~Applications Serial No. 08/275,120, Atty docket no. IMM1P003~~ No. 5,623,582, filed July 14, 1994, and ~~Serial No. 08/344,148, Atty docket no. IMM1P004~~ Patent No. 5,821,920, filed 11/23/94, both assigned to the assignee of the present invention and incorporated herein by reference in their entirety. In yet other embodiments, flexible members and/or couplings can be used in the embodiment of Figure 2a or 3, as described in copending U.S. Patent ~~Application serial no. 08/560,091, Atty. Docket no. IMM1P013~~ Patent No. 5,805,140, filed 11/17/95, and hereby incorporated by reference herein.

Replace the existing paragraph starting on Page 23, Line 21 with the following new paragraph.

When using a band drive system as described, the bands wrap around themselves on spindle 92, i.e., the spindle in effect grows in circumference. Band stretch is thus of possible concern; however, the stretch has been found to be well within the limits of the strain capabilities of the bands. In addition, there is a tendency for the drum 82 to spring back to the center of travel, where the band stretch is at its lowest. However, there are several ways to compensate for this spring effect. In the preferred embodiment, control software implemented by the computer 16 compensates for the stretch springiness by computing an equal and opposite force to the spring force based, for example, on a spring constant of the band or a value ~~form~~ from a look up table. In other embodiments, the bands 100a and 100b can be wrapped diagonally on spindle 92 so that the bands never wrap around themselves. However, this requires a wider spindle and a less compact mechanism. Alternatively, a spring can be provided on spindle 92 to compensate for the stretch of the bands 100a and 100b.

Replace the existing paragraph starting on Page 24, Line 34 through Page 25, Line 7 with the following new paragraph.

In other embodiments, other types of drive mechanisms can be used to transmit forces to linear axis member and receive positional information from member 64 along axis C. For example, a drive wheel made of a rubber-like material or other frictional material can be

positioned on ball slide 122 to contact linear axis member 64 along the edge of the wheel and thus convert linear motion to rotary motion and vice-versa. The wheel can cause forces along member 64 from the friction between wheel and linear axis member. Such a drive wheel mechanism is disclosed in ~~the co-pending Application Serial No. 08/275,120~~ Patent No. 5,623,582 as well as in U.S. Patent ~~Application Serial No. 08/344,148~~ No. 5,821,920. The drive mechanism can also be implemented in other ways, as explained above, as explained above with respect to Figure 5a.

Replace the existing paragraph starting on Page 25, Line 10 with the following new paragraph.

FIGURE 7 is a block diagram a computer 16 and an interface circuit 150 used in interface 14 to send and receive signals from mechanical apparatus 25. The interface circuit includes an interface card 152, DAC 154, power amplifier circuit 156, and sensor interface 158. In this embodiment, the interface 14 between computer 16 and mechanical apparatus 25 as shown in Figure 1 can be considered functionally equivalent to the interface circuits enclosed within the dashed line in Figure 7. Other types of interfaces 14 can also be used. For example, an electronic interface is described in U.S. Patent ~~Application Serial No. 08/461,170, Atty Docket No. 08/461,170~~No. 5,576,727, filed 6/5/95, assigned to the assignee of the present invention and incorporated herein by reference in its entirety. The electronic interface described therein has six channels corresponding to the six degrees of freedom of a mechanical linkage.

Replace the existing paragraph starting on Page 25, Line 29 through Page 26, Line 2 with the following new paragraph.

Digital to analog converter (DAC) 154 is coupled to interface card 152 and receives a digital signal from computer 16. DAC 154 converts the digital signal to analog voltages which are then sent to power amplifier circuit 156. DAC circuits suitable for use with the present invention are described in ~~co-pending patent application 08/374,288~~Patent No. 5,731,804, previously incorporated by reference. Power amplifier circuit 156 receives an analog low-power

control voltage from DAC 154 and amplifies the voltage to control actuators of the mechanical apparatus 25. A suitable power amplifier circuit 156 is described in greater detail in ~~co-pending patent application 08/374,288~~Patent No. 5,731,804. Sensor interface 158 receives and converts signals from sensors 162 to a form appropriate for computer 16, as described below.

Please replace the existing paragraph starting on Page 27, Line 1 with the following new paragraph.

In other embodiments, the interface 14 can be included in computer 16 or in mechanical apparatus 25. In yet other embodiments, the interface 14 can include a separate, local microprocessor that is dedicated to handling much of the force feedback functionality of the mechanical apparatus 25 independently of computer 16. Such an embodiment, and other related interface functions, are described in greater detail with respect to ~~co-pending patent appliatin 08/566,282, Atty docket no. IMM1P014~~Patent No. 5,734,373,hereby incorporated by reference herein.